1992 ELEMENTAL ANALYSIS OF BOUNDARY WATERS CANOE AREA LICHENS OF THE SUPERIOR NATIONAL FOREST

Final Report

by

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October 1993

Printed April, 1994

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Supported by

U. S. Forest Service

Contract 42-649

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ABSTRACT

In the final report on the lichens and air quality in the Boundary Waters Canoe Area (Wetmore, 1987) it was recommended that a restudy of the elemental analysis of lichens be done every five years. This report is on the first restudy done in 1992.

In this study four species of lichens were collected during June, 1992 at the same localities as the previous study. The methods used were the same as in the previous study.

The results of this study showed some increase in five elements (Al, Fe, Cu, Cr and K) in lichens. These elements may come from airborne dust or their increase may be due to random changes. ANOVA and pairwise comparisons by statistical analysis showed a significant increase in the element group {Al, Fe, Cr, S} in all species at most localities but a decrease in {B} at all localities. The Trap Lake locality was more freqently at the low end of the accumulation scale and Lac La Croix was more frequently at the high end. It is concluded that there probably has been no important change in the air quality in the wilderness. The recommendation is made that the periodic five-year restudy of elemental analysis be continued.

ACKNOWLEDGMENTS

The U. S. Forest Service personnel have been very helpful in assisting with the field work and analysis of the data. Dave Rugg, statistician in the NCFES, did the statistical analysis. Manfred Mielke assisted with valuable suggestions during this study. The study was made possible by funds from the U. S. Forest Service, Superior National Forest and NAS & PF Forest Health Protection. The assistance of all of these is gratefully acknowledged.

INTRODUCTION

Lichens are able to accumulate chemical elements in the excess of their metabolic needs depending on the levels in the substrate and air and, since lichens are slow growing and long lived, they serve as good summarizers of the environmental conditions in which they are growing. Chemical analysis of the thallus of lichens growing in areas of high fallout of certain elements will show elevated levels in the thallus. Toxic substances (such as sulfur) are also accumulated and determination of the levels of these toxic elements can provide indications of sub-lethal but elevated levels in the air (Wetmore, 1987).

During 1986 a complete study of lichens and air quality was done in the Boundary Waters Canoe Area (BWCA), including a species list and elemental analysis of three species at six localities. The report showed no elevated accumulation of elements at any locality. The report recommended that a restudy of elemental analysis be done every five years.

During June, 1992 all six of the elemental analysis localities used in the earlier study were revisited for new collections. One lichen species was added in the study for a better comparison with other regional studies (Wetmore, 1985, 1988a, 1988b, 1988c).

METHODS

Methods used in the present study were the same as those of the original study (Wetmore, 1987). All six of the previous localities were again sampled in June, 1992. At each locality a bag of each species was collected from branches of conifers. Lichens were cleaned but not washed. Three replicates were obtained from each bag of each species for each locality. Multi-element analysis was by ICP and sulfur by infra red absorption. In the original study three species were analyzed (Cladina rangiferina, Evernia mesomorpha, and Hypogymnia physodes). In the present study Parmelia sulcata was added to the three species previously used to provide a better comparison with other regional studies.

Total fluoride content was studied in two species (Evernia mesomorpha and Hypogymnia physodes) at two localities. Analyses were done with two replicates of the 1986 collections and also two of the 1992 collections. Samples were prepared by grinding and digestion with 0.05 N sulfuric acid and one drop of Brij-35 wetting solution in a 50 ml polypropylene tube for 15 minutes. Sodium hydroxide was then added and the sample shaken for 15 minutes. Fluoride was determined using the Orion combination electrode with continuous stirring after addition of 5 ml of 3 M NaOAc and 10 ml of 0.5 M Na Citrate buffers to control the interfering ions, particularly aluminum ions. Standards were also included with the unknowns.

RESULTS AND DISCUSSION

Table 1 gives the results of the analysis for all replicates arranged by species. Table 2 gives the means and standard deviations for each set of replicates. All reported values were above the lower detection limits of the instruments. Analytical splits were made from some samples and are indicated by "@" in the tables. In these analytical splits the lichens were ground and mixed before being divided into replicates to determine the instrument error. Table 3 gives the values from the

1986 study and the 1992 study arranged by species and locality.

One additional species (Parmelia sulcata) was included in the present study because it has been used in other regional studies at Isle Royale National Park (Wetmore, 1985), Voyageurs National Park (Wetmore, 1984), and Grand Portage National Monument (Wetmore, 1992). Mean values for this species from these other areas is included in Table 3.

Aluminum, iron, copper, potassium and chromium increased more often than the other elements. Boron decreased in all species at all localities and potassium decreased more often than it increased. The other elements showed mixed changes. No locality showed consistent increase or decrease in elemental levels. These increases may be due to random changes or they may indicate a trend that should be investigated. A comparison of the lichen standard from the two studies shows comparable values.

Table 4 gives the results of the analysis for fluorides (F) for the two species and two localities from collections made in 1986 and 1992. There is little difference between values for the two years.

Fluorides have been shown to be toxic to lichens (Nash, 1971, LeBlanc & Rao, 1971, Gilbert, 1971, and others). Fluoride literature has been summarized by Gilbert (1973) for the few studies done on lichens and fluorides. He states that the pattern of sensitivity to F is different that lichen sensitivity to sulfur dioxide. Fumigation studies have verified F damage at 5ppm F for 4 days (Nash, 1971) or 65 ppb for 12 hours (Comeau & LeBlanc, 1972). Damage to the lichen is evident

Table 4. Fluorine analysis of BWCA Lichens
Values in ppm of thallus dry weight

	1986	1992
Evernia mesomorpha		
Basswood Lake	2.6	3.2
Basswood Lake	2.0	2.8
Lac La Croix	1.5	1.3
Lac La Croix	1.5	0.8
Trout Lake	<.8	0.8
Trout Lake	<.8	0.8
Hypogymnia physodes		
	1986	1992
Basswood Lake	1.4	1.7
Basswood Lake	1.1	2.3
Lac La Croix	1.6	0.9
Lac La Croix	1.5	1.1
Trout Lake	1.2	1.0
Trout Lake	1.0	1.1
Lichen standard Cladina stellaris <.8		

by chlorotic spotting (Nash, 1971, Gilbert, 1973). The distance from the source where there is detectable accumulation in lichens seems to be restricted to about 7.5 miles (Gilbert, 1971). Nash (1971) reported levels in two lichens at 6000 meters from the source as 18-21ppm while levels 100m from the source were 174-220 ppm. There are very few literature reports on fluorides in lichens and the only one that reported F levels in either of the species analyzed in this study was Takala et al. (1978). They give accumulation values for Hypogymnia physodes in clean areas as 4.2-7.8 ppm while in polluted areas the levels reached 18.4-23.5 ppm. The levels in the BWCA for this species are below these levels for a clean locality. However, if the distance of detection is as short as 7.5 miles, as reported by Gilbert (1971), the BWCA localities may be too far away from any source to detect elevated levels. It may be concluded that the areas of the BWCA studied are not being damaged by fluorides from nearby iron mining.

STATISTICAL ANALYSIS

Introduction

Generally, one bag of lichens was collected from a site, cleaned, separated into groups (with different individuals in the groups), ground, and analyzed for chemical constituents. Occasionally, a composite sample was prepared and gound before being subsampled (these are noted in the data by an @ following the location name). The questions of interest are:

- is variability among independent samples larger than variability among composite subsamples?
- for a species, has there been a change in elemental composition from 1986 to 1992?
- within a year, and for a species, are there differences among locations? is there a geographical trend?
- are there differences between the BWCA and Rainbow Lake?

Variability

To answer this question the C. rangiferina data from 1992 was used -- the whole samples + average of subsamples as one data set, the subsamples as another -- since C. rangiferina was the only species with subsamples collected. The MSE was computed for each chemical element in each data set, and then compared using a F-test. Nine of the 16 elements showed significantly ($\alpha = .05$) higher variability among samples than among subsamples; for the other 7 elements there was no significant difference. Overall, these results provide strong evidence ($P < 0.00001$) that inter-sample variance is larger than within sample variance.

The variability due to instrument accuracy was lower than the variability due to population sampling. Indivdual lichen thalli will vary in accumulation depending on exposure and other factors. Perhaps a study should be done to examine different sampling methods to more accurately reflect the elemental accumulation at a locality. It may be that all thalli of a species at a locality should be cleaned and gound before dividing into replicates. The resulting elemental levels would then represent an average for the locality.

Inter- and intra-year comparisons

Approach

Break elements into related groups using correlations. Reduce dimensionality through principal components analysis, using correlations to adjust for differing scales of the variables, with an aim of explaining at least 80% of the variability. Run analyses of variance.

The principal components analysis resulted in six groups of elements among the 16 elements measured: Group A = {K, Zn, Cu, Pb, Ni}, Group B = {Ca, Mg, Mn, Cd}, Group C = {Al, Fe, Cr, S}, Groups D-F = {P}, {Na}, {B}. Relative to the raw data, the analysis data for {P} have been multiplied by 0.10; the analysis data for {B} have been multiplied by 10.0.

Results -- 1986 vs. 1992

For all six analysis groups, the ANOVA showed a significant Yr*Species*Locality interaction ($\alpha = 0.05$.), so these results are broken down by species. The element group {Al, Fe, Cr, S} showed an increase between 1986 and 1992 at a majority of the localities in all species, while the element {B} showed a decrease at all localities and species. All other element groups showed a mixed response.

1986 vs 1992

C. rangiferina

{K, Zn, Cu, Pb, Ni}
No between years differences.

{Ca, Mg, Mn, Cd}
Basswood 86 = 92 Isabella 86 < 92 La Croix 86 = 92 Saganaga 86 < 92 Trap 86 < 92 Trout 86 = 92

{Al, Fe, Cr, S}
Basswood 86 = 92 Isabella 86 = 92 La Croix 86 < 92 Saganaga 86 = 92 Trap 86 < 92 Trout 86 < 92

{P}
Basswood 86 = 92 Isabella 86 < 92 La Croix 86 > 92 Saganaga 86 < 92 Trap 86 > 92 Trout 86 > 92

{Na}
Basswood 86 > 92 Isabella 86 > 92 La Croix 86 < 92 Saganaga 86 > 92 Trap 86 > 92 Trout 86 = 92

{B}
1986 > 1992 for all localities; year effect is the same for all localities

E. mesomorpha

{K, Zn, Cu, Pb, Ni}
Basswood 86 = 92 Isabella 86 < 92 La Croix 86 = 92 Saganaga 86 = 92 Trap 86 < 92 Trout 86 < 92

{Ca, Mg, Mn, Cd}
No between years differences.

{Al, Fe, Cr, S}
Basswood 86 < 92 Isabella 86 < 92 La Croix 86 = 92 Saganaga 86 < 92 Trap 86 < 92 Trout 86 < 92

{P}
1986 < 1992 for all localities; year effect is the same for all localities

{Na}
Basswood 86 < 92 Isabella 86 < 92 La Croix 86 < 92 Saganaga 86 > 92 Trap 86 < 92 Trout 86 < 92

{B}
Basswood 86 > 92 Isabella 86 > 92 La Croix 86 > 92 Saganaga 86 > 92 Trap 86 > 92 Trout 86 > 92

H. physodes

{K, Zn, Cu, Pb, Ni}
Basswood 86 = 92 Isabella 86 > 92 La Croix 86 = 92 Saganaga 86 < 92 Trap 86 > 92 Trout 86 > 92

{Ca, Mg, Mn, Cd}
Basswood 86 < 92 Isabella 86 > 92 La Croix 86 < 92 Saganaga 86 > 92 Trap 86 = 92 Trout 86 = 92

{Al, Fe, Cr, S}
Basswood 86 < 92 Isabella 86 = 92 La Croix 86 < 92 Saganaga 86 < 92 Trap 86 < 92 Trout 86 < 92

{P}
Basswood 86 = 92 Isabella 86 < 92 La Croix 86 > 92 Saganaga 86 = 92 Trap 86 = 92 Trout 86 = 92

{Na}
1986 > 1992 for all localities; year effect is the same for all localities

{B}
Basswood 86 > 92 Isabella 86 > 92 La Croix 86 > 92 Saganaga 86 = 92 Trap 86 > 92 Trout 86 > 92

Results -- BWCA 1986

The results are summarized below using $\alpha = 0.05$. For all six analysis groups, the ANOVA showed a significant Species*Locality interaction, so these results are broken down by species. The error terms used for these comparisons were the same as those used for the Year differences above. The localities are arranged from low on the left to high on the right. Lac La Croix is the locality that is significantly isolated at the high end more frequently than any other locality. The Trap Lake locality is the most frequent isolated locality at the low end. There seems to be no other trend toward a geographical gradient from west to east for the intermediate localities.

Cladina rangiferina

{K, Zn, Cu, Pb, Ni}

Saganaga	Basswood Lake	Lac La Croix	Isabella Lake	Trout Lake	Trap Lake
		Lac La Croix	Isabella Lake	Trout Lake	Trap Lake
				Trout Lake	Trap Lake

{Ca, Mg, Mn, Cd}

Saganaga	Basswood Lake	Lac La Croix	Isabella Lake	Trout Lake	Trap Lake

{Al, Fe, Cr, S}

Saganaga	Trap Lake	Basswood Lake	Isabella Lake	Lac La Croix	Trout Lake

{P}

Isabella Lake	Basswood Lake	Saganaga	Lac La Croix	Trout Lake	Trap Lake
	Basswood Lake	Saganaga	Lac La Croix	Trout Lake	Trap Lake
				Trout Lake	Trap Lake

{Na}

Basswood Lake	Saganaga	Lac La Croix	Isabella Lake	Trout Lake	Trap Lake
				Trout Lake	Trap Lake

{B}

Basswood Lake	Saganaga	Trap Lake	Isabella Lake	Lac La Croix	Trout Lake

Evernia mesomorpha

{K, Zn, Cu, Pb, Ni}

Trout Lake	Isabella Lake	Trap Lake	Saganaga	Basswood Lake	Lac La Croix
	Isabella Lake	Trap Lake	Saganaga	Basswood Lake	Lac La Croix
				Basswood Lake	Lac La Croix

{Ca, Mg, Mn, Cd}
Trap Lake Trout Lake Basswood Lake Isabella Lake Saganaga Lac La Croix

{Al, Fe, Cr, S}
Trap Lake Saganaga Isabella Lake Trout Lake Basswood Lake Lac La Croix
Trout Lake Basswood Lake Lac La Croix

{P}
Trout Lake Isabella Lake Basswood Lake Saganaga Trap Lake Lac La Croix

{Na}
Isabella Lake Trap Lake Trout Lake Basswood Lake Saganaga Lac La Croix
Saganaga Lac La Croix

{B}
Isabella Lake Trout Lake Trap Lake Saganaga Basswood Lake Lac La Croix

Hypogymnia physodes

{K, Zn, Cu, Pb, Ni}
Saganaga Trout Lake Basswood Lake Lac La Croix Trap Lake Isabella Lake
Basswood Lake Lac La Croix Trap Lake Isabella Lake

{Ca, Mg, Mn, Cd}
Basswood Lake Trap Lake Trout Lake Lac La Croix Saganaga Isabella Lake
Trout Lake Lac La Croix Saganaga Isabella Lake

{Al, Fe, Cr, S}
Trap Lake Saganaga Isabella Lake Basswood Lake Trout Lake Lac La Croix

{P}
Isabella Lake Basswood Lake Trout Lake Trap Lake Saganaga Lac La Croix
Basswood Lake Trout Lake Trap Lake Saganaga Lac La Croix

{Na}
Isabella Lake Trap Lake Trout Lake Basswood Lake Lac La Croix Saganaga
Trap Lake Trout Lake Basswood Lake Lac La Croix Saganaga
Basswood Lake Lac La Croix Saganaga

{B}
Saganaga Trap Lake Trout Lake Basswood Lake Isabella Lake Lac La Croix
Trap Lake Trout Lake Basswood Lake Isabella Lake Lac La Croix

Results -- BWCA 1992

The results are and summarized below using $\alpha = 0.05$. For all six analysis groups, the ANOVA showed a significant Species*Locality interaction, so these results are broken down by species. The error terms used for these comparisons were from new ANOVAs which included the P. sulcata data. The Trap Lake locality is most frquently isolated at the low end and Lac La Croix is most frequently isolated at the high end.

Cladina rangiferina

{K, Zn, Cu, Pb, Ni}

Basswood Lake	Isabella Lake	Saganaga	Lac La Croix	Trap Lake	Trout Lake
	Isabella Lake	Saganaga	Lac La Croix	Trap Lake	Trout Lake
		Saganaga	Lac La Croix	Trap Lake	Trout Lake

{Ca, Mg, Mn, Cd}

Lac La Croix	Trout Lake	Basswood Lake	Saganaga	Trap Lake	Isabella Lake
				Trap Lake	Isabella Lake

{Al, Fe, Cr, S}

Basswood Lake	Isabella Lake	Saganaga	Trap Lake	Lac La Croix	Trout Lake
Basswood Lake	Isabella Lake	Saganaga	Trap Lake	Lac La Croix	Trout Lake

{P}

Lac La Croix	Basswood Lake	Trout Lake	Isabella Lake	Saganaga	Trap Lake
		Trout Lake	Isabella Lake	Saganaga	Trap Lake
			Isabella Lake	Saganaga	Trap Lake

{Na}

Isabella Lake	Saganaga	Basswood Lake	Trap Lake	Trout Lake	Lac La Croix

{B}

Basswood Lake	Saganaga	Trap Lake	Isabella Lake	Lac La Croix	Trout Lake

Evernia mesomorpha

{K, Zn, Cu, Pb, Ni}

Saganaga	Trap Lake	Trout Lake	Basswood Lake	Lac La Croix	Isabella Lake
		Trout Lake	Basswood Lake	Lac La Croix	Isabella Lake

{Ca, Mg, Mn, Cd}

Saganaga	Trout Lake	Trap Lake	Basswood Lake	Isabella Lake	Lac La Croix

{Al, Fe, Cr, S}

Trap Lake	Saganaga	Trout Lake	Basswood Lake	Isabella Lake	Lac La Croix

{P}

Basswood Lake	Trout Lake	Trap Lake	Isabella Lake	Saganaga	Lac La Croix

{Na}

Saganaga	Trap Lake	Isabella Lake	Trout Lake	Basswood Lake	Lac La Croix

{B}

Trap Lake	Isabella Lake	Basswood Lake	Trout Lake	Lac La Croix	Saganaga

Hypogymnia physodes

{K, Zn, Cu, Pb, Ni}

Trout Lake	Isabella Lake	Basswood Lake	Lac La Croix	Trap Lake	Saganaga
		Basswood Lake	Lac La Croix	Trap Lake	Saganaga

{Ca, Mg, Mn, Cd}

Trap Lake	Saganaga	Trout Lake	Basswood Lake	Isabella Lake	Lac La Croix
		Trout Lake	Basswood Lake	Isabella Lake	Lac La Croix
			Basswood Lake	Isabella Lake	Lac La Croix

{Al, Fe, Cr, S}

Isabella Lake	Trap Lake	Lac La Croix	Saganaga	Trout Lake	Basswood Lake

{P}

Trout Lake	Saganaga	Isabella Lake	Trap Lake	Basswood Lake	Lac La Croix

{Na}

Trap Lake	Isabella Lake	Basswood Lake	Trout Lake	Saganaga	Lac La Croix
	Isabella Lake	Basswood Lake	Trout Lake	Saganaga	Lac La Croix
		Basswood Lake	Trout Lake	Saganaga	Lac La Croix

{B}

Isabella Lake	Trap Lake	Trout Lake	Basswood Lake	Lac La Croix	Saganaga
	Trap Lake	Trout Lake	Basswood Lake	Lac La Croix	Saganaga
		Trout Lake	Basswood Lake	Lac La Croix	Saganaga

Parmelia sulcata

{K, Zn, Cu, Pb, Ni}

Lac La Croix	Basswood Lake	Saganaga	Trout Lake	Isabella Lake	Trap Lake

{Ca, Mg, Mn, Cd}

Basswood Lake	Trap Lake	Lac La Croix	Isabella Lake	Trout Lake	Saganaga
			Isabella Lake	Trout Lake	Saganaga

{Al, Fe, Cr, S}

Trap Lake	Isabella Lake	Saganaga	Lac La Croix	Basswood Lake	Trout Lake
Trap Lake	Isabella Lake	Saganaga	Lac La Croix	Basswood Lake	Trout Lake

{P}

Isabella Lake	Basswood Lake	Saganaga	Lac La Croix	Trout Lake	Trap Lake

{Na}

Trap Lake	Saganaga	Isabella Lake	Basswood Lake	Trout Lake	Lac La Croix
	Saganaga	Isabella Lake	Basswood Lake	Trout Lake	Lac La Croix
			Basswood Lake	Trout Lake	Lac La Croix
				Trout Lake	Lac La Croix

{B}

Isabella Lake	Lac La Croix	Basswood Lake	Trap Lake	Saganaga	Trout Lake

Discussion -- BWCA 1986 vs 1992

The reasons for the increase of the element group {Al, Fe, Cr, S} at most localities between 1986 and 1992 are unknown. All other groups except {B} had a mixed response with about as many localities increaseng and decreasing. The element {B} decreased at all localities over this time period. In both sample years the Trap Lake locality was most frequently isolated at the low end and the Lac La Croix locality was isolated at the high end. The Trap Lake locality is at the eastern end of the wilderness and Lac La Croix is in the northwestern part. This might indicate an air quality gradient, but the intermediate localities do not show any such trend from west to east.

Results -- BWCA 1992 vs. Rainbow Lake 1992

All four species were included in these comparisons. Data for each locality were averaged prior to analysis (note that this changes the error term from within location to between locations). There were no element groups for which the 1992 compositions from the BWCA and Rainbow Lake differed significantly ($\alpha = .05$).

CONCLUSIONS

Instrument variability is less than the variability of the lichen population at a locality.

An increase was noted in some elements, especially the group {Al, Fe, Cr, S}, and perhaps Cu and K, between 1986 and 1992. This increase may not be important because these increases may be due to random changes. Some of these five elements are not important components of air pollution but may be due to airborne dust.

The reason for the higher levels of element groups at Lac La Croix and the lower levels at Trap Lake probably is not due to a regional west-east gradient because the intermediate localities are not regularly arranged.

Table 1. Analaysis of BWCA Lichens
Values in ppm of thallus dry weight

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
C. rangiferina	579	1549	843	340	386	378	14.8	91.6	15.8	1.5	1.3	2.1	0.5	0.5	0.1	331	Saganaga
C. rangiferina	541	1418	731	319	360	346	14.9	79.5	14.9	1.5	1.3	2.2	0.5	0.6	0.1	391	Saganaga
C. rangiferina	505	1367	689	306	331	331	18.2	79.3	13.4	1.5	1.3	2.3	0.6	0.6	0.1	396	Saganaga
C. rangiferina	517	1359	721	312	276	264	15.3	82.7	13.1	1.5	1.2	2.3	0.5	0.6	0.2	426	Saganaga @
C. rangiferina	559	1459	700	320	298	289	16.0	77.4	14.1	1.6	1.2	2.2	0.6	0.6	0.2	418	Saganaga @
C. rangiferina	550	1413	700	315	285	273	15.3	79.0	14.1	1.5	1.1	2.0	0.5	0.5	0.2	445	Saganaga @
C. rangiferina	634	1707	1144	428	314	281	18.7	52.5	22.7	1.9	1.2	1.9	0.5	0.6	0.2	429	Trap Lake
C. rangiferina	506	1518	934	342	307	275	17.3	43.3	20.6	1.9	1.0	2.4	0.6	0.6	0.2	488	Trap Lake
C. rangiferina	495	1333	1015	401	309	276	16.1	46.4	19.3	1.8	1.1	2.3	0.6	0.6	0.2	482	Trap Lake
C. rangiferina	624	1610	1101	365	294	262	15.4	52.5	23.6	1.9	1.0	2.0	0.5	0.5	0.2	474	Trap Lake @
C. rangiferina	616	1580	1097	365	299	265	15.8	50.2	23.6	1.8	0.9	1.8	0.5	0.5	0.2	471	Trap Lake @
C. rangiferina	653	1643	1073	363	307	278	17.3	51.6	23.8	2.0	1.2	2.2	0.5	0.5	0.2	521	Trap Lake @
C. rangiferina	303	958	607	267	260	337	15.9	93.9	14.4	1.5	1.1	2.1	0.5	0.5	0.2	289	Basswood L
C. rangiferina	319	1038	662	274	235	283	14.4	82.6	14.1	1.5	1.1	2.1	0.5	0.5	0.2	293	Basswood L
C. rangiferina	358	1078	734	295	290	381	18.3	96.3	14.7	1.5	1.4	2.0	0.5	0.6	0.2	250	Basswood L
C. rangiferina	324	923	694	273	252	331	14.4	85.6	13.9	1.4	1.2	2.1	0.5	0.5	0.2	303	Basswood L @
C. rangiferina	353	1022	687	282	261	334	15.6	85.7	14.0	1.4	1.2	2.0	0.5	0.6	0.2	289	Basswood L @
C. rangiferina	362	1046	700	289	251	300	16.3	90.5	14.7	1.5	1.3	1.9	0.5	0.5	0.2	317	Basswood L @
C. rangiferina	285	982	396	243	410	565	36.6	15.5	11.6	1.5	1.1	2.5	0.7	0.7	0.2	443	Lac La Croix
C. rangiferina	288	950	381	231	413	568	35.1	14.5	11.2	1.6	1.3	2.9	0.8	0.8	0.2	400	Lac La Croix
C. rangiferina	309	1063	419	241	342	496	35.9	15.3	11.4	1.8	1.4	3.2	0.8	0.7	0.2	385	Lac La Croix
C. rangiferina	306	1038	416	248	387	533	33.2	15.4	11.3	1.8	1.4	3.0	0.8	0.8	0.2	406	Lac La Croix @
C. rangiferina	321	1071	418	256	384	522	34.0	15.9	11.3	1.8	1.3	3.2	0.8	0.7	0.2	464	Lac La Croix @
C. rangiferina	331	1102	441	260	385	518	36.4	16.5	11.5	1.9	1.5	3.2	0.8	0.9	0.2	446	Lac La Croix @
C. rangiferina	386	1890	643	370	449	898	29.5	31.7	30.1	1.9	1.4	1.8	0.7	0.6	0.1	782	Trout Lake
C. rangiferina	368	1892	657	381	419	883	28.2	35.9	28.6	1.8	1.5	1.4	0.6	0.5	0.1	808	Trout Lake
C. rangiferina	395	1903	673	390	486	1051	31.7	34.4	29.5	1.9	1.6	2.0	0.7	0.7	0.1	792	Trout Lake
C. rangiferina	425	1132	885	452	276	247	12.8	33.3	16.2	1.4	0.8	1.6	0.4	0.5	0.1	388	Isabella L
C. rangiferina	497	1268	1026	525	285	257	13.0	41.3	18.6	1.6	1.0	1.9	0.5	0.5	0.1	357	Isabella L
C. rangiferina	590	1414	1219	618	268	236	13.8	47.8	21.0	1.7	1.2	1.7	0.5	0.5	0.2	332	Isabella L
E. mesomorpha	491	2061	1241	320	599	726	28.8	24.2	31.3	2.4	3.2	4.5	0.8	1.1	0.1	1100	Saganaga
E. mesomorpha	596	2324	1499	362	605	727	32.5	30.0	33.4	2.5	3.8	4.7	0.8	1.1	0.1	1230	Saganaga
E. mesomorpha	680	2781	1994	433	584	717	33.8	42.6	42.3	2.9	4.4	4.0	1.0	1.1	0.2	982	Saganaga
E. mesomorpha	614	2319	899	352	471	510	37.1	25.5	37.4	3.3	2.5	4.3	1.0	1.2	0.3	992	Trap Lake
E. mesomorpha	524	2253	931	316	421	450	30.1	28.5	40.3	3.2	2.2	3.7	0.7	0.9	0.3	969	Trap Lake
E. mesomorpha	523	2227	1070	323	488	535	28.5	30.3	38.8	3.2	2.2	3.9	0.8	1.0	0.3	1010	Trap Lake
E. mesomorpha	511	2146	699	370	661	1172	44.5	28.2	34.6	3.6	2.9	4.5	1.1	1.5	0.2	1190	Basswood L
E. mesomorpha	489	1949	646	343	654	1206	42.8	25.4	33.4	3.6	2.9	4.7	1.1	1.4	0.2	1090	Basswood L
E. mesomorpha	498	2068	742	397	786	1486	51.2	30.4	44.4	4.0	3.4	5.2	1.3	1.7	0.2	1160	Basswood L
E. mesomorpha	681	2543	1069	461	926	1502	77.7	40.8	44.7	3.7	4.2	5.4	1.5	1.9	0.4	1190	Lac La Croix
E. mesomorpha	730	2650	1184	432	817	1255	63.8	40.7	36.0	3.4	3.4	4.9	1.8	2.4	0.4	1210	Lac La Croix
E. mesomorpha	690	2456	921	423	837	1275	88.0	34.2	36.4	3.6	3.6	6.4	1.4	1.7	0.5	1030	Lac La Croix
E. mesomorpha	553	2279	1145	383	654	1509	45.3	36.7	36.6	3.2	3.4	4.6	1.1	1.4	0.2	1290	Trout L
E. mesomorpha	498	1961	877	347	598	1346	47.0	32.6	31.6	2.9	3.1	4.6	1.0	1.2	0.2	1140	Trout L
E. mesomorpha	534	2127	969	370	647	1315	44.5	32.6	33.6	3.1	3.3	5.0	1.1	1.4	0.2	1090	Trout L

E. mesomorpha	526	2187	646	351	794	933	39.7	19.3	34.0	4.5	2.5	10.7	1.6	1.7	0.4	1300	Isabella L
E. mesomorpha	568	2382	662	372	728	851	42.9	21.7	38.1	4.9	2.6	10.3	1.5	1.6	0.4	1270	Isabella L
E. mesomorpha	585	2471	624	381	765	921	42.9	21.2	44.5	5.0	2.7	9.4	1.6	1.7	0.4	1250	Isabella L
H. physodes	710	2601	15825	660	879	1060	31.4	165.5	75.0	4.6	3.4	17.1	1.8	1.5	0.5	878	Saganaga
H. physodes	532	2224	21891	604	799	963	27.7	128.2	70.2	4.6	3.0	19.9	1.8	1.4	0.6	843	Saganaga
H. physodes	701	2732	17969	694	783	944	29.8	253.7	70.0	4.4	3.2	17.1	1.6	1.3	0.6	905	Saganaga
H. physodes	710	2780	13794	617	637	695	24.4	107.3	72.7	4.8	2.4	15.2	1.4	1.1	0.7	905	Trap Lake
H. physodes	629	2803	14700	586	615	703	18.0	102.4	76.2	4.6	2.3	14.6	1.4	0.7	0.7	952	Trap Lake
H. physodes	777	3113	11809	590	606	681	18.7	112.7	75.7	4.7	2.1	15.6	1.1	0.7	0.7	910	Trap Lake
H. physodes	846	3165	14826	773	888	1558	27.9	151.2	72.4	4.2	2.8	13.1	1.5	1.3	1.0	947	Basswood L
H. physodes	656	3029	16451	732	799	1291	25.7	144.6	68.0	4.0	2.7	13.7	1.4	1.2	1.1	884	Basswood L
H. physodes	633	2816	16526	705	870	1291	24.3	133.2	66.7	4.7	2.6	14.1	1.5	1.3	1.0	995	Basswood L
H. physodes	800	3145	25140	871	735	1189	30.4	184.1	74.8	4.5	2.8	13.1	1.7	1.2	1.4	869	Lac La Croix
H. physodes	719	3123	20500	868	809	1223	29.7	262.5	70.6	4.3	2.9	10.6	1.6	1.3	1.3	970	Lac La Croix
H. physodes	679	3050	20678	825	799	1290	33.2	221.5	71.3	3.8	2.6	10.8	1.5	1.1	1.2	964	Lac La Croix
H. physodes	679	2837	19043	720	713	1683	29.9	199.2	68.4	3.7	2.8	9.4	1.5	1.1	0.4	847	Trout L
H. physodes	653	2672	25716	689	664	1409	24.2	161.5	64.9	3.9	2.5	9.5	1.4	1.0	0.4	971	Trout L
H. physodes	592	2541	26947	668	651	1452	27.9	184.6	82.1	4.2	2.6	9.2	1.4	1.1	0.7	1080	Trout L
H. physodes	673	2587	19027	876	591	654	19.1	78.7	75.6	5.1	1.7	16.1	0.9	0.9	1.0	751	Isabella L
H. physodes	735	2814	19534	777	652	739	22.8	135.3	70.4	5.7	1.9	16.9	1.1	1.0	1.0	778	Isabella L
H. physodes	640	2678	19151	726	570	649	23.1	121.6	71.6	5.7	2.0	15.4	1.0	0.9	1.1	726	Isabella L
P. sulcata	1026	3073	3817	580	1277	1337	28.4	131.2	87.4	4.5	4.5	19.5	1.7	1.6	0.4	1070	Saganaga
P. sulcata	1261	3289	3077	548	1106	1168	25.3	228.3	84.7	4.3	5.3	15.8	1.4	1.3	0.3	1030	Saganaga
P. sulcata	1163	3068	3461	564	1075	1087	24.0	238.5	83.3	4.5	4.3	15.4	1.5	1.3	0.4	1140	Saganaga
P. sulcata	1335	3164	2721	605	829	779	18.2	97.3	101.5	5.7	4.2	31.8	1.3	1.0	0.4	1020	Trap Lake
P. sulcata	1493	3335	2677	655	928	850	21.6	98.9	109.5	5.8	4.4	19.7	1.5	1.2	0.5	1060	Trap Lake
P. sulcata	1491	3315	3396	638	891	826	22.2	96.7	112.0	6.1	4.9	19.2	1.5	1.2	0.5	1015	Trap Lake
P. sulcata	1053	2918	2571	507	1166	1399	29.1	98.6	79.4	5.3	3.9	14.4	1.5	1.4	0.5	1190	Basswood L
P. sulcata	942	2788	2409	491	1160	1368	27.3	90.2	72.7	5.2	3.8	14.4	1.6	1.4	0.5	1200	Basswood L
P. sulcata	999	3014	2642	536	1283	1598	30.8	95.3	79.6	5.7	4.5	15.5	1.7	1.6	0.5	1050	Basswood L
P. sulcata	1260	3556	2650	621	962	1249	38.7	112.7	78.7	4.3	3.8	13.2	1.7	1.3	0.4	1190	Lac La Croix
P. sulcata	1295	3403	2804	655	1208	1582	37.2	113.9	73.9	4.5	4.1	13.6	1.9	1.5	0.6	1240	Lac La Croix
P. sulcata	1141	3245	2485	579	997	1275	38.4	101.6	68.2	4.4	3.8	13.2	1.7	1.2	0.5	1220	Lac La Croix
P. sulcata	1589	3658	4552	704	1042	1755	40.8	127.9	79.8	4.1	5.3	15.4	1.9	1.4	0.4	1070	Trout L
P. sulcata	1101	2954	4056	582	1010	1867	29.6	126.9	80.6	4.0	5.1	15.3	2.0	1.5	0.4	1070	Trout L
P. sulcata	1170	3106	4534	657	1056	1978	29.9	158.9	88.8	4.3	5.0	15.7	2.1	1.7	0.3	1045	Trout L
P. sulcata	816	2534	4978	555	889	901	26.1	102.7	99.5	7.1	3.3	22.6	1.7	1.4	0.6	977	Isabella L
P. sulcata	844	2663	4154	525	917	970	30.1	83.3	82.2	6.9	3.5	19.8	1.7	1.4	0.6	969	Isabella L
P. sulcata	1026	2898	4256	577	808	860	26.8	125.7	78.4	6.6	3.7	16.2	1.6	1.4	0.6	1050	Isabella L
C. stellaris	200	673	231	286	451	573	80.3	20.2	18.3	2.6	1.2	14.3	1.3	1.2	0.2	429	Lichen std.
C. stellaris	201	681	239	291	467	578	81.6	20.8	17.9	2.5	1.3	14.8	1.2	1.1	0.2	437	Lichen std.
C. stellaris	194	621	224	280	440	540	80.2	19.4	17.3	2.7	1.3	14.7	1.3	1.2	0.2	427	Lichen std.
C. stellaris	197	652	228	282	455	555	82.0	19.9	17.1	2.8	1.6	15.0	1.5	1.3	0.3	416	Lichen std.
NBS-Peach	1226	3760	4442	1216	485	170	16.4	699.5	68.7	3.3	18.0	12.9	2.2	2.1	0.3	NA	NBS-Peach
NBS-Peach	1254	3799	4399	1224	481	171	17.6	692.6	67.7	3.2	18.3	12.1	2.1	2.4	0.3	NA	NBS-Peach
NBS-Peach	1190	3682	4332	1190	478	166	14.7	683.7	70.6	3.1	17.7	12.2	2.1	2.3	0.3	NA	NBS-Peach
NBS-Peach	1156	3493	4112	1143	449	169	16.1	641.2	72.4	3.1	16.9	12.3	2.0	2.3	0.3	NA	NBS-Peach
NBS-Peach	1234	3673	4338	1201	480	181	19.5	679.9	65.1	3.5	17.7	13.2	2.2	2.5	0.3	NA	NBS-Peach

Table 2. Summary of Analysis of BWCA Lichens
Values in ppm of thallus dry weight

Cladina rangiferina

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	541	1445	754	322	359	352	16.0	83.5	14.7	1.5	1.3	2.2	0.5	0.6	0.1	373	Saganaga
St. Dev.	37	94	80	17	28	24	1.9	7.0	1.2	<.1	<.1	0.1	<.1	<.1	<.1	36	Saganaga
Mean	542	1410	707	316	286	275	15.5	79.7	13.8	1.5	1.2	2.2	0.5	0.6	0.2	430	Saganaga @
St. Dev.	22	50	12	4	11	13	0.4	2.7	0.6	<.1	0.1	0.1	<.1	<.1	<.1	14	Saganaga @
Mean	545	1519	1031	390	310	277	17.4	47.4	20.9	1.9	1.1	2.2	0.6	0.6	0.2	466	Trap Lake
St. Dev.	77	187	105	44	4	4	1.3	4.7	1.7	<.1	0.1	0.3	<.1	<.1	<.1	32	Trap Lake
Mean	631	1611	1090	364	300	268	16.1	51.4	23.7	1.9	1.0	2.0	0.5	0.5	0.2	489	Trap Lake @
St. Dev.	20	31	15	1	6	8	1.0	1.1	0.1	0.1	0.1	0.2	<.1	<.1	<.1	28	Trap Lake @
Mean	327	1025	668	279	262	334	16.2	90.9	14.4	1.5	1.2	2.0	0.5	0.5	0.2	277	Basswood L
St. Dev.	28	61	64	15	28	49	2.0	7.3	0.3	<.1	0.2	<.1	<.1	0.1	<.1	24	Basswood L
Mean	346	997	694	282	255	322	15.4	87.3	14.2	1.5	1.2	2.0	0.5	0.5	0.2	303	Basswood L @
St. Dev.	20	65	6	8	6	19	1.0	2.8	0.4	<.1	0.1	0.1	<.1	<.1	<.1	14	Basswood L @
Mean	294	998	399	238	388	543	35.9	15.1	11.4	1.6	1.3	2.9	0.8	0.7	0.2	409	Lac La Croix
St. Dev.	13	58	19	6	40	41	0.7	0.5	0.2	0.2	0.1	0.4	0.1	0.1	<.1	30	Lac La Croix
Mean	320	1070	425	255	386	524	34.6	15.9	11.4	1.8	1.4	3.1	0.8	0.8	0.2	439	Lac La Croix @
St. Dev.	13	32	14	6	2	8	1.6	0.5	0.1	<.1	0.1	0.1	<.1	0.1	<.1	30	Lac La Croix @
Mean	383	1895	658	380	451	944	29.8	34.0	29.4	1.9	1.5	1.7	0.6	0.6	0.1	794	Trout L
St. Dev.	14	7	15	10	34	93	1.8	2.2	0.8	0.1	0.1	0.3	0.1	0.1	<.1	13	Trout L
Mean	504	1271	1043	532	276	247	13.2	40.8	18.6	1.6	1.0	1.7	0.4	0.5	0.2	359	Isabella L
St. Dev.	83	141	167	83	9	11	0.5	7.3	2.4	0.2	0.2	0.2	<.1	<.1	<.1	28	Isabella L

Evernia mesomorpha

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	589	2389	1578	372	596	723	31.7	32.3	35.7	2.6	3.8	4.4	0.9	1.1	0.2	1104	Saganaga
St. Dev.	95	364	383	57	11	6	2.6	9.4	5.9	0.3	0.6	0.3	0.1	<.1	<.1	124	Saganaga
Mean	554	2267	967	330	460	498	31.9	28.1	38.8	3.2	2.3	4.0	0.8	1.0	0.3	990	Trap Lake
St. Dev.	52	47	91	19	35	44	4.6	2.4	1.5	0.1	0.1	0.3	0.1	0.1	<.1	21	Trap Lake
Mean	499	2054	696	370	700	1288	46.2	28.0	37.5	3.8	3.1	4.8	1.2	1.5	0.2	1147	Basswood L
St. Dev.	11	100	48	27	74	172	4.5	2.5	6.0	0.2	0.3	0.4	0.1	0.1	<.1	51	Basswood L
Mean	700	2550	1058	438	860	1344	76.5	38.6	39.0	3.6	3.7	5.6	1.6	2.0	0.4	1143	Lac La Croix
St. Dev.	26	97	132	20	58	137	12.1	3.8	4.9	0.1	0.4	0.8	0.2	0.4	<.1	99	Lac La Croix
Mean	528	2123	997	367	633	1390	45.6	33.9	33.9	3.1	3.3	4.7	1.1	1.3	0.2	1173	Trout L
St. Dev.	28	159	136	18	31	104	1.3	2.4	2.5	0.2	0.1	0.2	0.1	0.1	<.1	104	Trout L
Mean	560	2346	644	368	762	902	41.8	20.8	38.9	4.8	2.6	10.1	1.6	1.7	0.4	1273	Isabella L
St. Dev.	30	145	19	15	33	45	1.9	1.3	5.3	0.2	0.1	0.6	0.1	0.1	<.1	25	Isabella L

Hypogymnia physodes

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	648	2519	18562	653	821	989	29.6	182.4	71.7	4.5	3.2	18.0	1.7	1.4	0.6	875	Saganaga
St. Dev.	100	263	3076	45	51	62	1.8	64.4	2.8	0.1	0.2	1.6	0.1	0.1	0.1	31	Saganaga
Mean	705	2898	13434	598	619	693	20.3	107.5	74.9	4.7	2.3	15.1	1.3	0.8	0.7	922	Trap Lake
St. Dev.	74	186	1479	17	16	12	3.5	5.1	1.9	0.1	0.2	0.5	0.2	0.2	<.1	26	Trap Lake
Mean	712	3003	15934	737	852	1380	26.0	143.0	69.0	4.3	2.7	13.6	1.5	1.3	1.0	942	Basswood L
St. Dev.	117	176	961	35	47	154	1.8	9.1	3.0	0.4	0.1	0.5	<.1	0.1	0.1	56	Basswood L
Mean	733	3106	22106	855	781	1234	31.1	222.7	72.2	4.2	2.8	11.5	1.6	1.2	1.3	934	Lac La Croix
St. Dev.	62	50	2629	26	40	52	1.9	39.2	2.2	0.3	0.1	1.4	0.1	0.1	0.1	57	Lac La Croix
Mean	641	2684	23902	692	676	1515	27.3	181.8	71.8	3.9	2.6	9.3	1.4	1.1	0.5	966	Trout L
St. Dev.	45	148	4253	26	32	147	2.9	19.0	9.1	0.2	0.1	0.2	<.1	0.1	0.1	117	Trout L
Mean	683	2693	19237	793	604	681	21.6	111.9	72.5	5.5	1.9	16.1	1.0	0.9	1.0	752	Isabella L
St. Dev.	48	114	264	76	42	51	2.2	29.6	2.8	0.4	0.1	0.7	0.1	0.1	<.1	26	Isabella L

Parmelia sulcata

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	1150	3143	3452	564	1153	1197	25.9	199.3	85.2	4.4	4.7	16.9	1.6	1.4	0.4	1080	Saganaga
St. Dev.	118	126	370	16	109	127	2.2	59.2	2.1	0.1	0.5	2.3	0.2	0.2	<.1	56	Saganaga
Mean	1440	3271	2931	633	883	818	20.7	97.6	107.6	5.9	4.5	23.6	1.4	1.1	0.5	1032	Trap Lake
St. Dev.	90	94	403	25	50	36	2.1	1.2	5.5	0.2	0.4	7.1	0.1	0.1	0.1	25	Trap Lake
Mean	998	2907	2540	512	1203	1455	29.0	94.7	77.2	5.4	4.1	14.8	1.6	1.5	0.5	1147	Basswood L
St. Dev.	55	113	119	23	69	125	1.7	4.3	3.9	0.2	0.3	0.6	0.1	0.1	<.1	84	Basswood L
Mean	1232	3401	2646	618	1056	1369	38.1	109.4	73.6	4.4	3.9	13.3	1.8	1.3	0.5	1217	Lac La Croix
St. Dev.	81	155	159	38	133	185	0.8	6.7	5.2	0.1	0.2	0.2	0.2	0.2	0.1	25	Lac La Croix
Mean	1286	3239	4381	648	1036	1867	33.4	137.9	83.1	4.1	5.1	15.5	2.0	1.5	0.4	1062	Trout L
St. Dev.	264	371	281	61	24	111	6.4	18.2	5.0	0.1	0.2	0.2	0.1	0.1	<.1	14	Trout L
Mean	895	2698	4463	552	871	910	27.6	103.9	86.7	6.9	3.5	19.5	1.7	1.4	0.6	999	Isabella L
St. Dev.	114	184	449	26	56	56	2.1	21.2	11.2	0.2	0.2	3.2	0.1	<.1	<.1	45	Isabella L

Cladonia stellaris

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	198	658	231	286	453	564	80.7	20.1	17.8	2.6	1.3	14.6	1.3	1.1	0.2	431	Lichen std.
St. Dev.	4	33	7	6	14	20	0.8	0.7	0.5	0.1	<.1	0.3	0.1	0.1	<.1	5	Lichen std.

NBS Peach

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	1223	3747	4391	1210	481	169	16.2	691.9	69.0	3.2	18.0	12.4	2.1	2.3	0.3	NA	NBS-Peach
St. Dev.	32	59	55	17	4	2	1.4	8.0	1.4	0.1	0.3	0.4	<.1	0.2	<.1	NA	NBS-Peach

Table 3. Comparison of 1986 and 1992 BWCA Elemental Analyses
Values in ppm of thallus dry weight

<u>Cladina rangiferina</u>

	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
1986																	
Mean	392	1505	495	245	225	172	25.5	27.6	13.7	1.5	1.6	2.2	0.6	0.4	0.2	460	Saganaga
Std. dev.	109	41	10	7	9	7	2.2	8.3	1.4	0.1	0.1	0.1	0.2	<.1	<.1	49	
1992																	
Mean	541	1445	754	322	359	352	16.0	83.5	14.7	1.5	1.3	2.2	0.5	0.6	0.1	373	Saganaga
St. Dev.	37	94	80	17	28	24	1.9	7.0	1.2	<.1	<.1	0.1	<.1	<.1	<.1	36	
1986																	
Mean	770	2328	740	346	210	156	36.4	52.4	20.2	2.1	1.7	1.2	0.6	0.4	0.2	513	Trap Lake
Std. dev.	125	366	149	1	16	14	13.6	10.9	0.9	0.1	0.4	0.4	0.1	<.1	<.1	95	
1992																	
Mean	545	1519	1031	390	310	277	17.4	47.4	20.9	1.9	1.1	2.2	0.6	0.6	0.2	466	Trap Lake
St. Dev.	77	187	105	44	4	4	1.3	4.7	1.7	<.1	0.1	0.3	<.1	<.1	<.1	32	
1986																	
Mean	367	1496	455	230	256	210	24.5	59.5	14.2	1.4	1.3	1.5	0.7	0.4	0.1	435	Basswood Lake
Std. dev.	35	155	9	16	18	14	0.2	43.0	1.3	0.1	<.1	0.3	<.1	<.1	<.1	25	
1992																	
Mean	327	1025	668	279	262	334	16.2	90.9	14.4	1.5	1.2	2.0	0.5	0.5	0.2	277	Basswood Lake
St. Dev.	28	61	64	15	28	49	2.0	7.3	0.3	<.1	0.2	<.1	<.1	0.1	<.1	24	
1986																	
Mean	497	1822	529	315	256	213	27.5	26.7	12.5	1.4	1.9	1.1	0.6	0.4	0.1	462	Lac La Croix
Std. dev.	116	262	81	43	46	37	2.1	12.2	0.8	<.1	<.1	0.2	0.1	<.1	<.1	12	
1992																	
Mean	294	998	399	238	388	543	35.9	15.1	11.4	1.6	1.3	2.9	0.8	0.7	0.2	409	Lac La Croix
St. Dev.	13	58	19	6	40	41	0.7	0.5	0.2	0.2	0.1	0.4	0.1	0.1	<.1	30	
1986																	
Mean	639	2328	607	331	231	263	31.5	57.9	16.7	1.6	2.0	1.0	0.6	0.4	0.1	490	Trout Lake
Std. dev.	104	131	107	26	74	88	3.2	33.7	2.2	0.2	0.3	<.1	0.1	0.1	<.1	4	
1992																	
Mean	383	1895	658	380	451	944	29.8	34.0	29.4	1.9	1.5	1.7	0.6	0.6	0.1	794	Trout Lake
St. Dev.	14	7	15	10	34	93	1.8	2.2	0.8	0.1	0.1	0.3	0.1	0.1	<.1	13	
1986																	
Mean	335	1568	601	254	261	214	28.0	47.5	16.6	1.6	1.8	1.6	0.6	0.4	0.2	470	Isabella Lake
Std. dev.	22	105	5	22	42	30	5.4	1.3	1.5	0.1	<.1	0.6	0.4	<.1	<.1	42	
1992																	
Mean	504	1271	1043	532	276	247	13.2	40.8	18.6	1.6	1.0	1.7	0.4	0.5	0.2	359	Isabella Lake
St. Dev.	83	141	167	83	9	11	0.5	7.3	2.4	0.2	0.2	0.2	<.1	<.1	<.1	28	

Evernia mesomorpha

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
1986																	
Mean	521	2324	677	311	493	429	45.3	67.3	27.4	2.4	5.4	5.0	1.1	1.0	0.3	1041	Saganaga
Std. dev.	83	294	21	30	38	45	9.9	36.5	0.3	0.3	0.1	0.3	0.1	<.1	0.2	51	
1992																	
Mean	589	2389	1578	372	596	723	31.7	32.3	35.7	2.6	3.8	4.4	0.9	1.1	0.2	1104	Saganaga
St. Dev.	95	364	383	57	11	6	2.6	9.4	5.9	0.3	0.6	0.3	0.1	<.1	<.1	124	
1986																	
Single val.	534	2562	1006	277	371	296	26.1	29.7	34.1	2.5	5.0	4.4	0.7	0.7	0.2	948	Trap Lake
1992																	
Mean	554	2267	967	330	460	498	31.9	28.1	38.8	3.2	2.3	4.0	0.8	1.0	0.3	990	Trap Lake
St. Dev.	52	47	91	19	35	44	4.6	2.4	1.5	0.1	0.1	0.3	0.1	0.1	<.1	21	
1986																	
Mean	482	2380	780	343	660	726	38.8	25.4	30.1	3.0	6.0	4.9	0.9	1.1	0.2	1221	Basswood Lake
Std. dev.	66	215	373	1	81	116	1.9	1.7	1.4	0.1	0.1	0.7	0.1	0.2	0.1	126	
1992																	
Mean	499	2054	696	370	700	1288	46.2	28.0	37.5	3.8	3.1	4.8	1.2	1.5	0.2	1147	Basswood Lake
St. Dev.	11	100	48	27	74	172	4.5	2.5	6.0	0.2	0.3	0.4	0.1	0.1	<.1	51	
1986																	
Single val.	603	2746	1159	479	966	1037	50.4	23.8	29.0	3.3	6.6	5.3	1.2	1.5	0.3	1373	Lac La Croix
1992																	
Mean	700	2550	1058	438	860	1344	76.5	38.6	39.0	3.6	3.7	5.6	1.6	2.0	0.4	1143	Lac La Croix
St. Dev.	26	97	132	20	58	137	12.1	3.8	4.9	0.1	0.4	0.8	0.2	0.4	<.1	99	
1986																	
Mean	383	1826	657	290	578	668	38.3	31.6	24.3	2.1	4.9	6.5	1.0	1.0	0.2	1029	Trout Lake
Std. dev.	90	405	1	63	83	50	5.6	4.6	3.9	0.5	0.4	1.4	<.1	0.1	<.1	168	
1992																	
Mean	528	2123	997	367	633	1390	45.6	33.9	33.9	3.1	3.3	4.7	1.1	1.3	0.2	1173	Trout Lake
St. Dev.	28	159	136	18	31	104	1.3	2.4	2.5	0.2	0.1	0.2	0.1	0.1	<.1	104	
1986																	
Mean	398	2057	1524	355	645	585	25.4	69.0	32.6	2.8	4.9	6.1	0.8	1.0	0.2	1005	Isabella Lake
Std. dev.	46	205	605	58	107	117	3.8	10.6	2.9	0.5	0.3	1.7	0.1	0.1	0.1	92	
1992																	
Mean	560	2346	644	368	762	902	41.8	20.8	38.9	4.8	2.6	10.1	1.6	1.7	0.4	1273	Isabella Lake
St. Dev.	30	145	19	15	33	45	1.9	1.3	5.3	0.2	0.1	0.6	0.1	0.1	<.1	25	

Hypogymnia physodes

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
1986																	
Mean	724	3190	20375	617	461	431	40.6	271.3	63.0	2.8	3.6	18.0	1.6	0.9	0.7	1014	Saganaga
Std. dev.	22	47	2532	2	26	19	1.6	81.7	3.1	<.1	0.2	1.9	0.1	0.1	<.1	16	
1992																	
Mean	648	2519	18562	653	821	989	29.6	182.4	71.7	4.5	3.2	18.0	1.7	1.4	0.6	875	Saganaga
St. Dev.	100	263	3076	45	51	62	1.8	64.4	2.8	0.1	0.2	1.6	0.1	0.1	0.1	31	
1986																	
Mean	721	3455	25072	572	321	295	27.5	97.1	88.4	3.9	4.1	18.4	1.3	0.6	0.8	904	Trap Lake
Std. dev.	181	167	11148	27	21	54	4.5	29.1	24.4	0.3	1.2	3.4	0.1	<.1	<.1	37	
1992																	
Mean	705	2898	13434	598	619	693	20.3	107.5	74.9	4.7	2.3	15.1	1.3	0.8	0.7	922	Trap Lake
St. Dev.	74	186	1479	17	16	12	3.5	5.1	1.9	0.1	0.2	0.5	0.2	0.2	<.1	26	
1986																	
Single val.	681	3326	15432	663	530	508	32.6	146.2	64.2	3.2	4.1	16.1	1.6	0.9	0.8	915	Basswood Lake
1992																	
Mean	712	3003	15934	737	852	1380	26.0	143.0	69.0	4.3	2.7	13.6	1.5	1.3	1.0	942	Basswood Lake
St. Dev.	117	176	961	35	47	154	1.8	9.1	3.0	0.4	0.1	0.5	<.1	0.1	0.1	56	
1986																	
Single val.	929	3775	22004	905	582	588	32.9	134.5	47.3	3.5	4.8	20.8	1.6	1.0	0.7	1033	Lac La Croix
1992																	
Mean	733	3106	22106	855	781	1234	31.1	222.7	72.2	4.2	2.8	11.5	1.6	1.2	1.3	934	Lac La Croix
St. Dev.	62	50	2629	26	40	52	1.9	39.2	2.2	0.3	0.1	1.4	0.1	0.1	0.1	57	
1986																	
Mean	712	3499	19688	695	486	588	32.5	187.5	57.0	3.0	4.1	15.8	1.7	1.0	0.6	1061	Trout Lake
Std. dev.	111	276	1918	80	7	24	4.3	10.3	3.2	0.4	1.1	2.8	0.2	0.1	<.1	80	
1992																	
Mean	641	2684	23902	692	676	1515	27.3	181.8	71.8	3.9	2.6	9.3	1.4	1.1	0.5	966	Trout Lake
St. Dev.	45	148	4253	26	32	147	2.9	19.0	9.1	0.2	0.1	0.2	<.1	0.1	0.1	117	
1986																	
Mean	552	2809	34218	807	577	586	22.7	330.1	68.3	3.8	4.5	26.9	1.7	0.9	1.4	803	Isabella Lake
Std. dev.	147	332	2369	104	88	29	2.8	14.4	1<.1	<.1	0.6	4.2	0.1	0.1	0.2	46	
1992																	
Mean	683	2693	19237	793	604	681	21.6	111.9	72.5	5.5	1.9	16.1	1.0	0.9	1.0	752	Isabella Lake
St. Dev.	48	114	264	76	42	51	2.2	29.6	2.8	0.4	0.1	0.7	0.1	0.1	<.1	26	

Parmelia sulcata 1992

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	Locality
Mean	1150	3143	3452	564	1153	1197	25.9	199.3	85.2	4.4	4.7	16.9	1.6	1.4	0.4	1080	Saganaga
St. Dev.	118	126	370	16	109	127	2.2	59.2	2.1	0.1	0.5	2.3	0.2	0.2	<.1	56	
Mean	1440	3271	2931	633	883	818	20.7	97.6	107.6	5.9	4.5	23.6	1.4	1.1	0.5	1032	Trap Lake
St. Dev.	90	94	403	25	50	36	2.1	1.2	5.5	0.2	0.4	7.1	0.1	0.1	0.1	25	
Mean	998	2907	2540	512	1203	1455	29.0	94.7	77.2	5.4	4.1	14.8	1.6	1.5	0.5	1147	Basswood Lake
St. Dev.	55	113	119	23	69	125	1.7	4.3	3.9	0.2	0.3	0.6	0.1	0.1	<.1	84	
Mean	1232	3401	2646	618	1056	1369	38.1	109.4	73.6	4.4	3.9	13.3	1.8	1.3	0.5	1217	Lac La Croix
St. Dev.	81	155	159	38	133	185	0.8	6.7	5.2	0.1	0.2	0.2	0.2	0.2	0.1	25	
Mean	1286	3239	4381	648	1036	1867	33.4	137.9	83.1	4.1	5.1	15.5	2.0	1.5	0.4	1062	Trout Lake
St. Dev.	264	371	281	61	24	111	6.4	18.2	5.0	0.1	0.2	0.2	0.1	0.1	<.1	14	
Mean	895	2698	4463	552	871	910	27.6	103.9	86.7	6.9	3.5	19.5	1.7	1.4	0.6	999	Isabella Lake
St. Dev.	114	184	449	26	56	56	2.1	21.2	11.2	0.2	0.2	3.2	0.1	<.1	<.1	45	

Parmelia sulcata values from other regional studies.

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	
Mean VOYA	1509	3465	2499	469	413	512	32.2	82.1	73.7	4.4	2.3	14.2	2.4	0.7	0.3	871	Voyageurs NP
Mean ISRO	1473	3809	2649	524	431	392	23.9	113.9	122.2	8.6	3.6	30.3	1.1	0.6	0.4	1050	Isle Royale NP
Mean GRPO	1200	3226	4423	545	739	883	30.7	146.6	88.0	6.5	5.4	10.5	2.1	1.6	0.6	1098	Grand Portage NM
Mean BWCA	1167	3110	3402	588	1034	1270	29.1	123.8	85.6	5.2	4.3	17.3	1.7	1.4	0.5	1089	BWCA 1992

Lichen standards - *Cladina rangiferina*

Species	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	S	
Mean 1986	199	698	217	273	399	488	83.3	18.6	17.8	2.6	1.1	11.7	0.8	0.9	0.2	437	Lichen std.
Mean 1992	198	658	231	286	453	564	80.7	20.1	17.8	2.6	1.3	14.6	1.3	1.1	0.2	431	Lichen std.

It does not appear that there has been significant change in the air quality of the BWCA since 1986.

RECOMMENDATIONS

The original recommendation that elemental analyses be restudied every five years is again made here. Continued periodic study will help to determine whether the increase in certain elements is due to random changes or part of a trend with some significance.

A study of methods of lichen sampling is recommended to find a way to reduce the variability due to differences in individual thalli. The BWCA is weel suited for this study because of the abundance of suitable lichens for easy cleaning.

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